Direct Simulations Of Nonlinear Three-Dimensional Wave And Wave-Group Dynamics

Dick K.P. Yue
Department of Ocean Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139
phone: (617) 253- 6823 fax: (617) 258-9389 email: yue@mit.edu
Award #: N000149810790
http://web.mit.edu/spiral/frames

LONG-TERM GOAL

The ultimate goal is to develop and apply effective and robust computational tools for nonlinear dynamics of three-dimensional waves and wave groups. Of immediate interests are the spatial/temporal coherence of such waves and the nonlinear mechanism of such coherent structures. This work is the first step of a long-term effort to obtain robust realistic simulations of nonlinear wave-field evolution including wind, current, and shallow water (bottom variation) effects.

OBJECTIVES:

To develop and improve efficiency and robustness of the high-order spectral (HOS) method for long-time/large-space simulations of nonlinear wave-field evolutions. To develop methodologies for data assimilation and forecasting of nonlinear wave-field evolution dynamics. To study the coherence of three-dimensional steep waves and the mechanism for the development of such coherence structures and properties.

APPROACH

Direct simulations using HOS are performed to understand the nonlinear dynamics of three-dimensional ocean waves and wave groups. The HOS method is based on a Zakharov equation mode-coupling framework but is generalized to include up to an arbitrary order $\boldsymbol{M}$ in wave steepness and a large number $\boldsymbol{N}$ of wave modes. The method obtains exponential convergence with $\boldsymbol{N}$ (and $\boldsymbol{M}$) and computational effort only linearly proportional to $\boldsymbol{M}$ and $\boldsymbol{N}$. The computational power of HOS allows us to perform large-scale simulations of nonlinear three-dimensional wave-field evolutions including wave-current and long-short wave interactions. HOS computations can also serve to corroborate experimental and field data, confirm analytical perturbation predictions, and provide initial and boundary-condition specifications for wave-basin investigation or fully-nonlinear simulations of specific localized wave events.

WORK COMPLETED

The main work completed includes:

- Development and application of a highly efficient and accurate high-order spectral (HOS) method for long-time large-space simulations of nonlinear wave-field evolutions. Computations are performed to study the spatial/temporal coherence structures of three-dimensional waves.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **Direct Simulations Of Nonlinear Three-Dimensional Wave And Wave-Group Dynamics**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Massachusetts Institute of Technology,Department of Ocean Engineering,77 Massachusetts Avenue,Cambridge,MA,02139**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

- Development a multiple-level iterative optimization scheme for wave reconstruction and data assimilation of two- and three-dimensional nonlinear wave-fields. Applications of the scheme to space-time reconstruction of two- and three-dimensional nonlinear wave-fields using a single- or multiple-point measurements.

- Application of HOS simulations and wave reconstruction algorithm to physical wave-basin measurements of steep three-dimensional wave fields. Direct comparisons of the HOS simulations to the wave-basin measurements.

RESULTS

The main results obtained in the past year are on the reconstruction of nonlinear wave-fields. One key purpose of wave reconstruction is to generate a proper initial wave-field using wave records (of limited duration) at one or more fixed points. With the constructed wave-field as initial conditions, HOS simulations provide all information of the wave-field in time and space. The results show that the developed wave-reconstruction algorithm is quite effective for the realization of nonlinear wave-fields using a single- or multiple-point measurements.

For two-dimensional waves, direct quantitative comparisons between the HOS simulations and experimental measurements in a 80m long tank are obtained. In figure 1*a*, the HOS simulation result of the reconstructed wave-field is compared to the specified wave probe record for about 10 dominant wave periods. The agreement between them is excellent. The time and space evolution of the wave-field from the HOS simulation is shown in figure 1*b*.

The reconstruction of three-dimensional wave-fields is also obtained using both synthetic data and wave-basin measurements. Figure 2 shows a snapshot of the three-dimensional wave-field, constructed based on three-probe synthetic records, and the comparison between the HOS simulation result and the specified wave records. The computed results agree well with the given data. Using the wave-basin (46m x 30m) experimental data provided by Professor M.H. Kim of the Texas A & M University, we reconstruct the steep bull's eye waves and conduct HOS simulations of the nonlinear evolution of such waves. The computed bull's eye wave elevations compare well with the experimental measurements.

IMPACT/APPLICATION

The understanding and modeling of three-dimensional wave dynamics are essential to the design and safety of very large floating structures such as the proposed Mobile Offshore Base (MOB). Our work provides the rational theoretical and computational basis of comparison, calibration, and mutual validation of wave simulations and field measurements. This work also provides the wave environment input to related simulation efforts such as those for the evaluation of wave loads and motions.

TRANSITIONS

A paper addressing the developed scheme for reconstruction and forecasting of three-dimensional nonlinear wave-field evolutions is in preparation for submission to the *Journal of Fluid Mechanics*. A second paper focusing on the comparisons of the HOS simulations to the wave-basin and field experimental measurements will be submitted to the *Journal of Applied Ocean Research*.

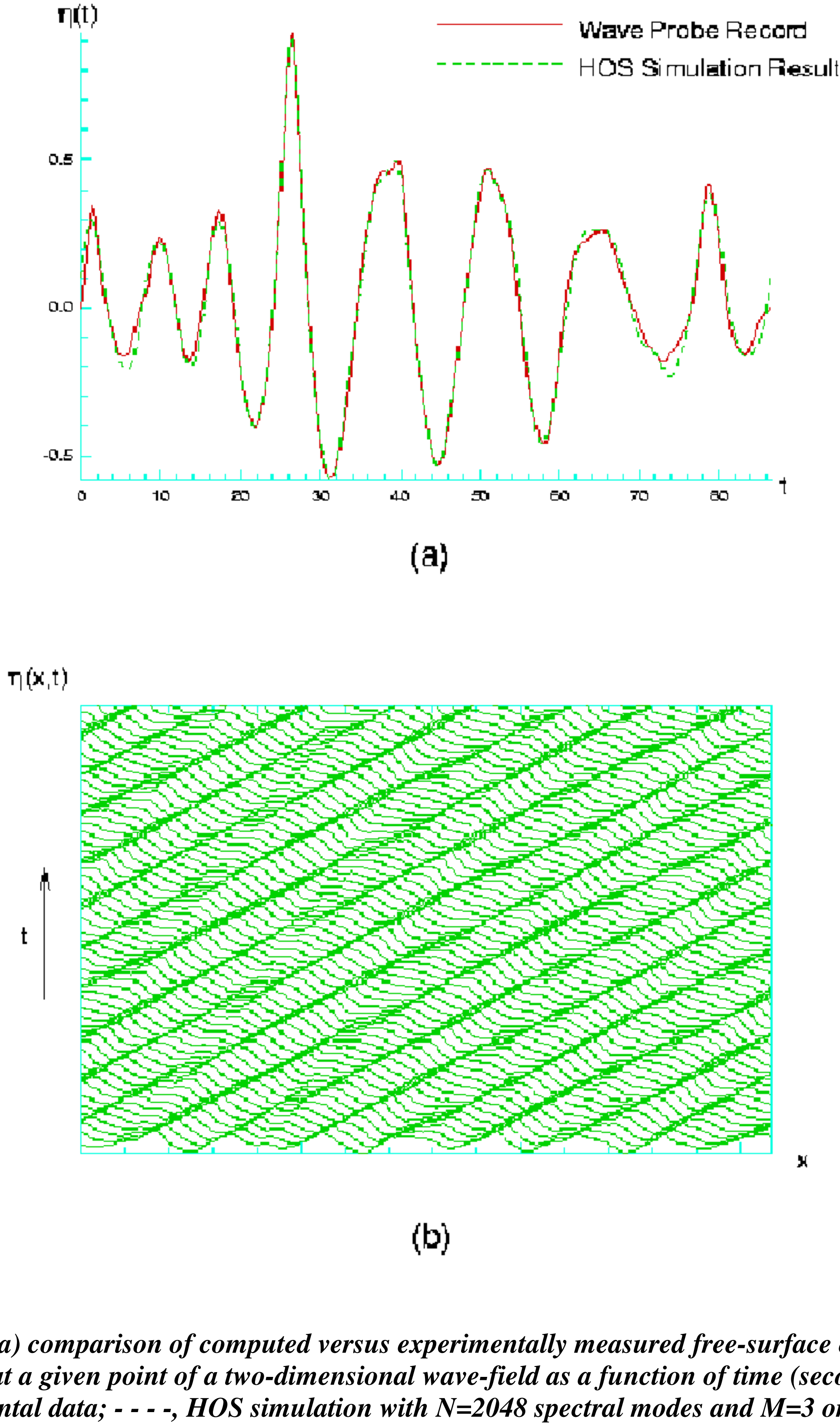

Figure 1. (a) comparison of computed versus experimentally measured free-surface elevation (*10 meters) at a given point of a two-dimensional wave-field as a function of time (seconds): ------, experimental data; - - - -, HOS simulation with N=2048 spectral modes and M=3 order; and (b) evolution of the reconstructed wave-field obtained by the HOS simulation.

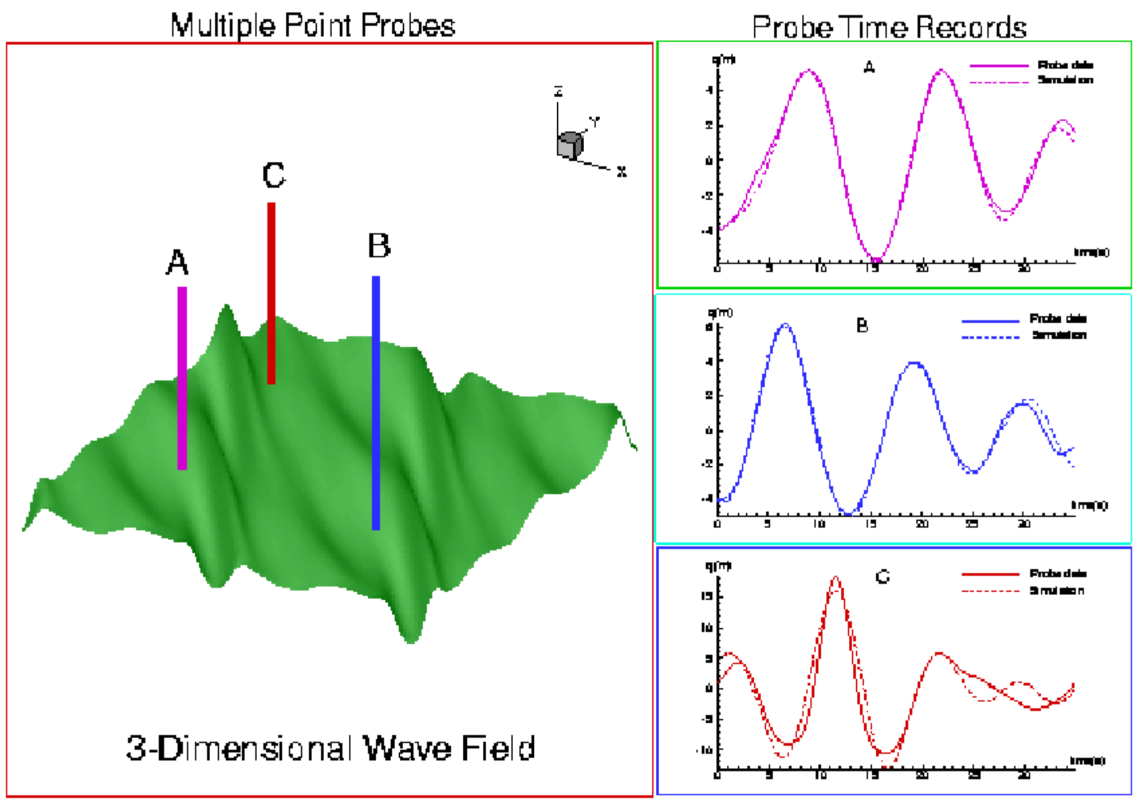

Figure 2. A snapshot of the three-dimensional wave-field constructed using specified probe time records at points A, B, and C; and comparisons of the HOS simulated (- - - -, N=1024 x 1024, M=3) versus specified (------) free-surface elevations at points A, B and C as a function of time.